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Education & Training in Multi- and Hyperspectral Measurement Engineering and Quality Assurance

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Abstract. Multi- and hyperspectral imaging is one of the most promising measurement techniques in respect of quality assurance or production metrology. Therefore, it is obvious to develop some training and education concepts for practice. This publication presents some approaches for training methods regarding hyperspectral imaging in a spectral range from 220 nm up to 1700 nm. Technological restrictions require different measurement, imaging and radiation equipment as well. Based on current researches in the group of quality assurance and industrial image processing, this training concept was assembled respecting latest equipment, software and knowledge. A future goal is to involve students in the processes of development and point out technological deficiencies of this system.

1. Introduction and principle of measurement

To demonstrate the importance of multi- and hyperspectral imaging as a part of university education, some typical hyperspectral imaging applications are listed and explained below [1]:

- Agricultural and food
- Medical and forensic
- Surface- defects detection

Many applications of multi- and hyperspectral imaging profit from the fact that this measurement technique is non- tactile. Therefore, there is no influence at the surface, as would be the case with tactile measurement. Push- broom- imaging means that one image line is acquired over the whole resolvable spectral range. By initializing a relative movement of the object against the imaging system, another image line can be acquired. The result is a so called spectral cube, which is realized by stitching every image line. Therefore, the spectral cube contains the information of wavelength and intensity as a function of the pixel index. The intended goal for the concept of the current hyperspectral investigation is to get information in a wide spectral range. Due to technical limitations, different measurement equipment is required. The hardware setup contains different imaging-systems for different spectral ranges. Limitations are given, for example, by the semiconductor-technology of the sensor systems or the optical system. Therefore, it is advisable to design a training program that makes trainees familiar with those different components and software.

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2. Hard- and software education

2.1. Hardware education

All relevant hardware components, except the UV-radiation source, are shown in figure 1. The UV-radiation source for the required spectral range is one of the significant hardware realization problems. Because of current development processes, the UV-radiation source is not shown. Further information can be found in [2] and [3].

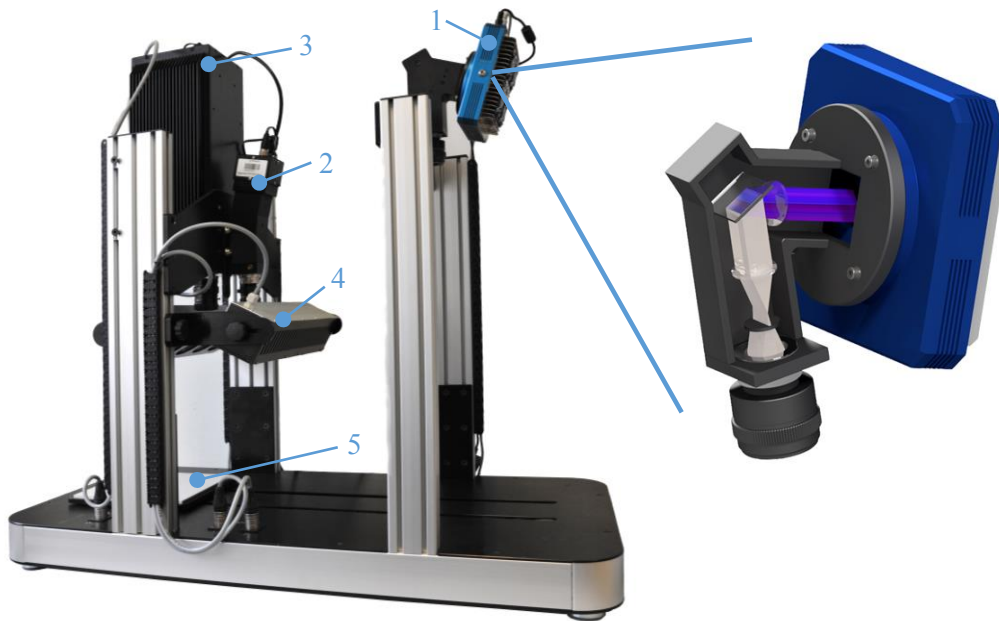


Figure 1. Imaging hardware components and functional principle of the imaging system.

2.1.1. Multi- and hyperspectral imaging systems

The given numbers in figure 1 are referenced in table 1, which presents some important properties of the applied imaging systems. Furthermore, figure 1 gives a cutaway view of one imager to demonstrate the optical principle of push-broom-imaging.

Table 1. Key properties of applied hyperspectral imaging systems (1-3).

		Spectral range	Spectral Resolution	Pixel Size	Bit depth	Sensor
(1)	UV	220 – 400 nm	< 2 nm	13 x13 μm	16 bit	Backlit CCD
(2)	VIS/NIR	400 – 1000 nm	10 nm	8 x 8 μm	12 bit	CMOS
(3)	SWIR	950 – 1700 nm	3.2 nm	30 x 30 μm	14 bit	InGaAs

2.1.2. Radiation and illumination sources (4), positioning system (5). Radiation and illumination sources are currently in development. First investigations in the VIS/NIR/SWIR range was done by using standard- halogen illumination sources. Alternatives super continuous lasers or gas discharging lamps. As mentioned above, information regarding the UV-radiation source can be found at the corresponding

references. A linear positioning system is used to preserve the relative movement of the object against the imaging system, which is necessary to realize push-broom-imaging.

2.1.3. Achievable hyperspectral range. To get an overview of achievable spectral behavior, figure 2 shows the quantum efficiency as a function of the wavelength for each of the three sensor systems. However, it must be noted that these values represent only the sensor system. Loss of intensity by transmission and other influences are not considered.

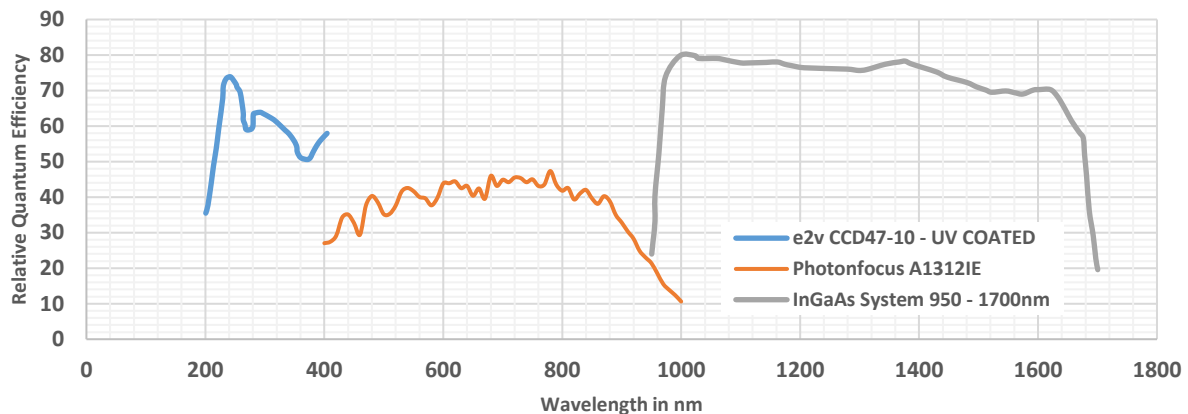


Figure 2. Theoretical achievable hyperspectral range.

2.2. Software education

2.2.1. Software for data acquisition. Currently, data acquisition is done by the manufacturer's software. This state is representative for a typical initial situation. But it is also a goal of the training programme to point out alternative approaches for data acquisition, as described later.

2.2.2. Software for data interpretation. For interpreting the acquired data, the software EVINCE is used. It features hyperspectral data management, visualization, PCA- methods and PLS- regression models as well. An example of data that was interpreted by EVINCE is shown in figure 3.

2.2.3. Further developments for software harmonization. As already mentioned, software for data acquisition and stitching of spectral cubes is not harmonized. Additionally, at this point it is possible to begin upcoming degree theses.

3. Education & Training Program and Example Applications

3.1. Education and training concept

A step-by-step education concept was developed to transfer as much knowledge as possible. Respecting many technological restrictions and measurement typical problems, the following steps contain and simulate the most important issues for understanding these measurement techniques and applying them. The structure could be interpreted as a sequential algorithm.

3.1.1. Preparation. The first task for trainees is to prepare themselves and study the basic knowledge, which is necessary for understanding further steps. That basic knowledge consists of the functional principle of push-broom-imaging, physical optical models and the basics in reflection spectroscopy as well. The supervisor should check the preparation state of the student and should correct possible misinterpretations and help to fill knowledge gaps.

3.1.2. First image acquisition. In this step, the trainees should notice the effect of rectification, such as the smile- and keystone effect. The first image acquisition should be done using only one of the three imaging systems. Another important task for the trainees is to understand and calculate a suitable sample rate finding a balance between sub- and oversampling. Furthermore, white balancing must be done for each system.

3.1.3. Full hyperspectral image acquisition and image processing. For handling this demands, it is necessary to understand and work with multidimensional arrays. It is advisable to integrate some programming tasks for stitching image data that must be solved by the trainees using easy to learn script languages, such as MATLAB or Python.

3.1.4. Extracting information for quality assurance. Finally, the acquired data must be interpreted to get significant information. This will be performed using the EVINCE software. An example is given in figure 3.

3.2. Example application

For visualization of the discussed topics, an example of a hyperspectral measurement task is given in figure 3. This example was done interpreting data acquired in the spectral range of NIR/SWIR. The scanned pill blister has on cell filled with water, which can be analysed and detected by utilising *PCA* and *PLS* function of EVINCE.

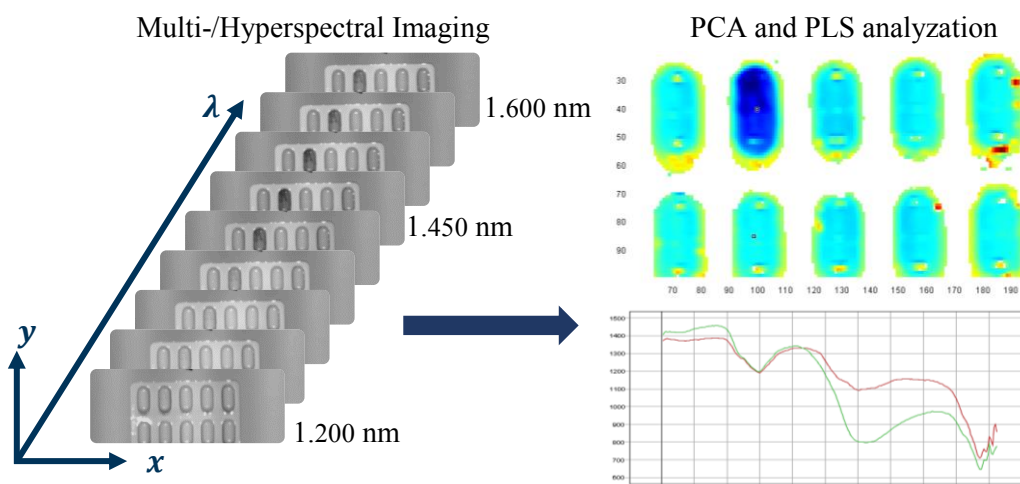


Figure 3. Example application. Hyperspectral data interp.

4. Conclusion

The developed education program represents typical applications and issues of hyperspectral imaging using push- broom- imaging as good as possible. It is ensured that students will be confronted with typical advantages and disadvantages of this system and measurement method as well. It is also a goal of this programme to make students aware of this system and its issues to recruit them for theses.

5. References

- [1] Manickavasagan A and Jayasuriya H 2014 *Imaging with Electromagnetic Spectrum Applications in Food and Agriculture*
- [2] Illmann R 2018 *Aufbau eines breitbandigen UV- Bestrahlungssystems für die bildgebende UV- Spektroskopie* (Technische Universität Ilmenau)
- [3] Illmann R 2018 Wide range UV irradiation system for imaging reflection spectroscopy *SPIE Commercial + Scientific Sensing and Imaging* (in press)